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Early Mathematical Experiences of Successful African American Scientists, Engineers, and Mathematicians

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In 2000, the National Council of Teachers of Mathematics (NCTM) published the *Principles and Standards for School Mathematics* (NCTM, 2000). These standards, created by a team of researchers, educators, and mathematicians, provided the United States with a detailed framework for teaching mathematics in schools. The first principle in the document, *The Equity Principle*, emphasizes the value of diversity and equity in mathematics. Recognizing that success in mathematics is not reserved for one group of students, the NCTM attempted to address the specific needs of students of color who, traditionally, have had limited access to educational opportunities in mathematics. The authors contend:

> All students, regardless of their personal characteristics, backgrounds, or physical challenges, must have opportunities to study—and support to learn—mathematics. Equity does not mean that every student should receive identical instruction; instead, it demands that reasonable and appropriate accommodations be made as needed to promote access and attainment for all students. (p. 27)

Inherent in the NCTM Standards is the idea that, when given the opportunity, all children can learn mathematics content as well as the problem-solving and critical-thinking skills involved in the study of mathematics. By investing in and utilizing these standards, schools (supposedly) ensure that all students, regardless of race, ethnicity, gender, or class, have equitable access to and opportunity to participate in a high-quality educational system that will provide them with a sound foundation in all subjects, including mathematics and science.

Unfortunately, the United States continues to struggle in its effort to meet the goals outlined in the Standards despite the efforts of the educational and research communities. Findings from the Third International Mathematics and Science Study (TIMSS) indicate that students from other industrialized nations continue to outperform U. S. students in mathematics and science as indicated by proficiency during the twelfth grade year of high school (National Science Board, 2012). Furthermore, a significant gap exists between African American, Latina/o,

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and Native American students and their White and Asian peers on standardized measurements of mathematics proficiency.

Although some may argue that improving the performance of people of color in science, technology, engineering, and mathematics (i.e., STEM) as a means of ensuring the nation's economic viability is sound, it creates another question: *If the US were not experiencing a shortage of trained individuals in these fields and the scientific and technological future and related economic system were not in jeopardy, would there still be a need to improve the performance and representation of people of color in STEM?* Some researchers (e.g., Perry, Moses, Wynne, Cortés, & Delpit, 2010) are encouraging the research community to look at the problem as one related to ethics, morality, and basic human rights. They argue that despite the economic, scientific, or technological needs in the United States, those responsible for shaping the educational system must make every attempt to ensure that all students, regardless of race, culture, class, or gender, have equitable access to STEM.

The aforementioned researchers view equitable access and opportunity as an inherent civil right. Moses and Cobb (2001), for example, argue that "math literacy in urban and rural communities throughout the country is an issue as urgent as the lack of registered voters in Mississippi was in 1961" (p. 5). In my opinion, positioning STEM access as a civil rights issue offers a more valid argument for the need to improve the performance and representation of people of color in STEM than the argument related to the needs of the nation's scientific and technological workforce. However, steps toward improvement can only be taken by providing adequate and equitable access to educational opportunities in these fields. Unfortunately, many existing educational programs are failing to attract and retain those who currently account for a large share of the workforce: people of color and women. Consequently, many educators, researchers, and policymakers are seeking to understand the factors related to the under-representation of people of color in STEM fields.

In spite of current educational research regarding this issue, there remains a significant omission. A review of the literature reveals that much of the current research focuses on simply describing the problem of poor representation and performance among African American students. What is lacking is research that focuses on the characteristics of African American students who are successful in STEM. Instead of focusing on the factors that keep these students out of STEM, we must focus on the elements of the lives of African American students that have allowed many to persist.

This study reported here represents a part of a larger study designed to identify and investigate the critical life elements related to the development of successful African Americans in STEM. In this paper, I present my investigation of the students' early experiences that influenced their successful participation in

STEM fields throughout their academic careers. Specifically, I explored the following question as it related to African American graduate students: *What factors were perceived to have contributed to the students' initial interest in science, engineering, or mathematics?* The findings provide valuable information to schools, educators, policymakers, and researchers on how to effectively prepare *some* children, including those of color, for induction into tomorrow's scientific community and *all* children for life in our science and technology driven society.

Methods

Study Participants

The participant group included 32 African American students, equally divided by gender (16 women, 16 men), who were engaged in graduate work in science, engineering, or mathematics. Eight of these students were pursuing terminal degrees in mathematics. The balance of the participants was pursuing graduate degrees in fields that relied heavily on mathematics (e.g. physics, computer science, mechanical engineering). In addition to race and gender, the participants were selected based on socioeconomic status and geographic region. In terms of socioeconomic status, 13 students (roughly 41%) self-identified as lower class; 15 students (roughly 47%) self-identified as middle class; the remaining four students (roughly 13%) self-identified as upper middle class or upper class. In terms of the regional diversity of the participant group, 23 (71.9%), 4 (12.5%), 2 (6.3%), and 2 (6.3%) were from the southern, midwestern, northeastern, and western regions of the United States, respectively. One student did not identify a particular state or region of origin based on a military background. Because I examined life histories in the study, these classifications are based on the participants' perceptions of their socioeconomic status and geographic region during their adolescence rather than categories that I imposed upon them.

Data Collection and Analysis

The study relied heavily on each participant's personal narrative, as interviews were the sole source of data. Each student participated in one 60 to 90 minute interview. The interview had to be sufficiently open-ended to capture each student's unique life history. However, I had to maintain some degree of consistency across the interviews. In an effort to meet both of these criteria, the study used an open-ended, semi-structured interview protocol. Initial coding revealed a set of unorganized first-level codes. These first-level codes were then grouped and organized to develop second-level codes, also known as pattern codes, which allow for a more in-depth understanding of the themes and concepts involved in the study and the ways in which they interacted with and related to each other (Miles

& Huberman, 1994). Finally, these second-level codes were used to develop a set of themes related to the success of African American students in STEM.

Findings

The majority of the students involved in the study indicated that their early lives (ages 4–12) were characterized by an emerging interest in STEM and concepts related to these areas (e.g. problem solving). Furthermore, students perceived fewer obstacles to their success during this period of their development. It is most interesting that the majority of the students' experiences with STEM took place within their communities and was mediated by family members and other community members as opposed to the formal school environment.

Four major themes emerged from the analysis of the data. The first was that all students were involved in experiences that allowed a significant *level of participation* in STEM. This theme refers to any experiences that created access to STEM as well as an opportunity to develop interest in STEM. Second, all of the students experienced some form of *positive personal intervention* by another person. These interventions were aimed at developing, encouraging, and refining the students' interest and performance in science, engineering, or mathematics. Third, all students possessed perceptions of these fields that involved some sort of *positive outcome*. These outcomes ranged from actual (e.g., "good" grades on a mathematics test) and immediate (e.g., feels of accomplishment after solving a mathematics problem) to perceived (e.g., admiration from family members) and anticipated (e.g., access to college or employment in the future). Finally, all of the students believed they possessed *intrinsic qualities* that qualified and prepared them for their involvement with STEM. The participants often characterized this theme as a *genetic* connection to their parents, a God given *gift* or *blessing*, or a *calling* to STEM. The remainder of this paper focuses on two of these themes: level of participation and positive personal intervention.

Level of Participation

Level of participation refers to the availability and quality of experiences aimed at developing the students' interest and competence in STEM. Early in their lives, students took advantage of activities that exposed them to knowledge and skills related to STEM and gave them access to projects that allowed them to apply the knowledge they possessed. As children, 31 of the 32 students interviewed were introduced to the concepts that they would later study in graduate school during these early experiences. Some of these experiences were fairly formal and similar to those one would have in a science or mathematics classroom.

For example, Jackie explained how she was first introduced to biology when, at the age of six, her mother gave her a microscope for Christmas:

> What I do remember clearly that day is raiding the refrigerator and putting everything under the scope. Making slides of onions. Making slides of lettuce. Pulling out hairs and making slides and spending literally all day making slides and looking at stuff under the scope. And the microscope is still, to this day, what I really like. I like being able to see things that you can't see otherwise.

This example demonstrates a level of access that would not normally be found in a child's home and illustrates the importance of out-of-school experiences in shaping a child's interests. Other students described early experiences with STEM that were also not as formal, but did involve equipment and skills related to STEM.

Some students were introduced to and became interested in STEM through play. In most cases, these experiences were not related directly to the content involved in any of these fields, nor did the students explore any of the skills employed by scientists, engineers, and mathematicians. Instead, the instruments and experiences related to their play inspired the students to begin to explore STEM. Angela, a doctoral student in mathematics, explained how a simple contest with her grandfather evolved into an interest in mathematics. During these contests, she would race against her grandfather in an attempt to solve a mathematics problem:

> I think I got to use a calculator and he just got to use pen and paper. He would give me problems and we would race to see who could get it the fastest. And that's when my first interest in math came because I always wanted to beat him.

This informal experience allowed Angela to explore mathematics and to develop a degree of familiarity with the discipline. It should be noted, however, that these less formal experiences were not always as explicitly linked to STEM as Angela's was. Some students reported experiences in their play that introduced them to STEM in a more implicit way. For example, Derrick described the ways in which his mother helped him develop the skills he would use as an engineer later in life by insisting that he design and build his own toys.

The examples presented are similar in that they all occur in the students' homes or communities, which was common to most of the participants. However, there were two students who recalled early experiences with mathematics, science, or engineering that occurred within the elementary school classroom. Reginald, currently conducting research in Human Computer Interactions, recalled the influence of the Apple 2E computer stations in his third grade classroom. He stated that the computer's capacity to perform functions ranging from teaching phonics to word processing sparked his interest in computer science. It should be noted, although Reginald's teacher was in the classroom, Reginald did not describe her or him as a mediator of those experiences. Instead, he was responsible for exploring his interest in computers on his own. Derrick, pursuing a Master's degree in Electrical Engineering, also recalled his early experiences with science and mathematics taking place within his school. Interestingly, he attended a preschool that focused specifically on mathematics and science. His experiences at this school provided him with advanced preparation in mathematics and science. Consequently, when he entered elementary school, he was already familiar with much of the mathematics and science content.

Many of the students, particularly those from low socioeconomic backgrounds, explored science and mathematics through books or television. Once they learned to read, many of the study participants became avid readers. In his interview, Rodney described how his love of reading provided him with access to information about computers:

> At an early age, I was reading about computers. I saw that reading satisfies your desires to learn about something. So I started reading about computers and I had subscriptions to PC magazine….I got in trouble because I didn't know how to pay for the stuff and after the free trial was over, I let my mom deal with all of that….So I put the connection together that if there was something out there that I wanted to learn, it was available in these forums that I was reading.

The love of reading and the influence of books were particularly significant in the lives of students from low-income homes. The presence of books in the home or public libraries in the neighborhood provided these students with inexpensive access to information about STEM. Other students were introduced to STEM through television. Jared explained how he was influenced by a television series related to science:

> I use to watch [the television show,] Mr. Wizard's World. That was one thing that I remember. I don't know if that was my inspiration as for why science became fascinating to me, but that's one of my earliest memories of being fascinated with how the world works. [Mr. Wizard would do] things that would incorporate physics and chemistry….I just thought it was cool. It was one of my favorite shows.

Although television programs did not offer students direct, hands-on interactions with STEM, the medium did allow students to engage in limited exploration of these fields. Consequently, television programming similar to Mr. Wizard's World was particularly valuable for students who may not have had the financial resources or parental guidance needed to incorporate STEM activities into the everyday pastimes of the home. Each of these examples demonstrates the importance of both in-school and extracurricular participation in activities both explicitly and implicitly linked to STEM.

Positive Personal Intervention

Although all students, regardless of ethnicity, gender, or class have STEM-related experiences in the home, many fail to see these experiences as such and to connect what occurs in the home with their school lives. This statement was not true for the students involved in this study. In each of their lives, there were people who were able to not only forge these connections but also encourage the development of the child as a scientist, engineer, or mathematician. Positive personal intervention refers to the role of specific contributors to the development of the student as a scientist, engineer, or mathematician. According to the interviews, these contributors possessed two distinct characteristics. First, all interventions involved some level of interaction between the student and the intervener. High levels of interaction are defined as those that involve direct and often extended contact between the student and the intervener. Low levels of interaction, on the other hand, were not as intimate and often were distant and brief. The second characteristic was the intervener's level of knowledge of STEM and the associated careers. Similar to the level of interaction, level of knowledge also ranged from high to low. A contributor with a high level of knowledge possessed intimate knowledge of STEM and the associated careers as well as the ways in which one prepared for and achieved success in these careers. A low level of knowledge was characterized by a rudimentary understanding of STEM and the associated careers.

The students described two types of interveners in their early experiences: role models and supporters. They characterized each type of positive personal intervention by level of knowledge (high to low) and level of interaction (high to low). Role models were those who students saw as similar to themselves in terms of a variety of characteristics such as socioeconomic status, race, or gender. However, the direct interaction between a role model and the student was minimal. Role models possessed a high degree of knowledge concerning STEM and the professions associated with these areas. However, the student usually only *observed* a role model's participation in these areas. Supporters were defined as those who were not involved with science, engineering, or mathematics, but did participate in direct interactions with the student.

During their early lives, parents and community members fulfilled the roles of supporters and role models in the students' lives. The students most often reported personal intervention that consisted of direct, nonverbal encouragement from supporters in their lives. The term direct, in this case, refers to interaction solely between the child and the supporter. The supporter encouraged the student by mediating activities related to STEM. For example, Michael described the ways in which his family supported his interest in mathematics:

> [My family members] weren't the ones saying, "You need to go to college." They weren't saying that. But in a way they were saying that by making sure I got to be in a position to do everything I needed to do. They didn't say it, but they did it. It was by their actions.

In this example, the family was able to offer direct encouragement through their involvement with Michael. However, it should be noted that Michael did not recall his family making any explicit *verbal* statements aimed at persuading him to study mathematics. Direct nonverbal encouragement also occurred when supporters gave students the opportunity to demonstrate their abilities. By doing this, the supporters expressed their confidence in the students' proficiencies in a given area. Joseph, later to become an electrical engineer, explained how people in his community encouraged his early interest in mathematics:

> People…whenever they dealt with the money or anything that dealt with numbers, I was just real quick. I don't know who the person was that picked up on it but at some point, people, when they had math stuff to do, they just said, "Well, get Joseph to do it."

This example was similar to Michael's in that Joseph did not receive any explicit verbal encouragement aimed at motivating him to develop an interest in mathematics. Instead, community members encouraged his interest in mathematics by providing him with opportunities to demonstrate his abilities. Furthermore, this type of encouragement also reflected the value that the larger community placed on Joseph's abilities, and gave him the perception that, because of his abilities, he had a valuable role in the community.

A number of students spoke about the influence of role models their early development as scientists, engineers, and mathematicians. Most often, students who interacted with role models described their families as middle or upper class. These students often spoke of family members who demonstrated success in STEM or related fields. Adrienne explained that her uncle, a medical doctor, influenced her decision to pursue science. In this case, the student did not have a close relationship with her uncle. However, her perceptions about his career and her family's appreciation for his profession had a profound influence on her later decision to pursue a career in STEM. Another student, Travis, mentioned the influence his older brother had on his development as a mathematician:

> I really looked up to my brother…and I just remember him one day saying how much he liked math. I…remember him saying something about learning trigonometry and I wanted to know what that was. I remember very shortly after that I grew to pick up math and discover that I had an aptitude for it.

There were other students in the participant group who had parents, siblings, or other family members who were involved in science, engineering, or mathematics. However, most of them described the relationships they had with these individuals as more direct and therefore, more indicative of a supporter relationship.

In each of these examples, the student was involved in a positive interaction with a person acting as a supporter or role model. These people were responsible for mediating many of the students' early experiences with STEM. Through their actions, they were able to encourage the interests the students were developing in these areas.

Discussion

Three factors characterized most of the students' early experiences with STEM. First, experiences, although related to STEM, were also relevant to the students' lived experiences. For example, at six years old, Jackie did not use her microscope to examine the phenotypic expression (i.e., red eyes versus black eyes, wings versus no wings) of Drosophilae (the fruit fly)—a common curricular objective in biology. Instead, she was creating slides of familiar objects found within her home. As opposed to a tool of science, the microscope was seen as a tool for investigating the world around her. The same can be said of the other students' experiences: the majority of their experiences built on their prior knowledge and were relevant to their world. Some researchers are urging teachers to utilize this finding in their instruction. Ladson-Billings (1994) argues that effective teachers scaffold or build bridges between the knowledge students' carry with them from their communities and what is being taught in the classroom in an effort to facilitate the learning process. By using cultural referents to impart knowledge, skills, and attitudes, teachers not only empower their students academically but also socially, emotionally, and politically. As opposed to being placed at a disadvantage because of the discontinuities that exist between their culture and the culture of the school, students who work within the context of a culturally relevant curriculum find that their cultural knowledge actually serves as a foundation for the knowledge they learn in the classroom.

Second, in addition to exposure to STEM, the science and mathematics experiences in the home also provided hands-on and direct access to these subjects. For example, the contests between Angela and her grandfather did not simply introduce her to mathematics. In addition to presenting mathematical concepts, the game also allowed her to apply knowledge she possessed, hone the skills she was developing, and cultivate both new knowledge and skills. This particular characteristic of the experiences, however, was most apparent in the lives of students from middle and upper class home and communities. Students from low-income homes had limited access to these types of experiences. Instead, they relied on the more intangible STEM experiences presented in books and television programs.

Finally, in each of these examples, the exploration and subsequent learning were directed, at least in part, by the student. Consequently, students not only experienced significant levels of participation in areas related to STEM but also they were involved in the direction and development of the activities that facilitated their learning. It should be noted, however, that the adults involved in each of these situations played a very critical role. In all of these cases, family and community members were responsible for encouraging the student's interests and strengthening the connections between the child's experiences and the areas of STEM.

It is important to note that only two of the 32 students (both from schools outside of the Southeastern region of the United States) involved in the study recalled any influence from their schools during their early lives and only one of these two students remembered the positive influence of teachers at the school. This finding in addition to the ones summarized above points to two important ideas concerning the early preparation of African Americans in STEM. First, the findings suggest the positive influence that early involvement in science and mathematics at home and in the community can have on children. Informal experiences mediated by family members in the students' homes likely prepared the students in the study for success in these fields later in life.

Second, these findings support other studies, which have revealed a severe lack of effective mathematics and science preparation at the elementary school level. For example, research on science and mathematics education at the elementary school level revealed that that less than half (49%) of elementary school classes use science and mathematics objects each day (National Education Association, 2002). According to Malcolm and Anderson (2000), elementary school teachers deem instruction related to science and mathematics as less critical to child development when compared to teaching that focuses on language development, play, creative arts, and motor activities. Most students, regardless of race, receive little mathematics instruction and even less science instruction during elementary school. Research has shown, however, that structured mathematics and science lessons in the elementary classroom improve students' performance in high school (Novak & Musonda, 1991). A renewed commitment to mathematics and science preparation at the elementary level may result in a larger pool of potential African American scientists, engineers, and mathematicians to the nation's middle and high schools.

These findings have implications in educational curricula, teacher training, classroom practice, educational policy, and informal education programs (e.g., afterschool and museum programs). If the United States is to continue to move forward into its scientifically and technologically based future, it must begin to cultivate a scientifically and mathematically literate populace. However, in order to do so, the educational community must improve its capability to provide effective STEM education to all students; including those that are often marginalized by the current educational system (i.e. student of color, poor students, and immigrant students). Furthermore, these changes must be systemic and incorporate early childhood and elementary education as critical areas of improvement. Only then will we begin to provide our children with the skills and knowledge necessary to authentically participate in the world in which they will one day live.

At the Symposium

The conversation during the symposium focused on two key points. First, participants were interested in the idea of STEM education and its connections to social justice and democratic participation. This interest represented an important framework for the rest of the symposium. Second, the participants spent a great deal of time discussing the systemic and structural changes that are needed in order to create STEM education that prepared all children for participation in tomorrow's world. Specifically, the participants explored classroom practice, educational policy, and teacher development. The conversations resulted in several key recommendations for improving STEM education, specifically, as it applies to marginalized communities.

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